



# **OGV Clean Fuel Regulation Investigation of Operational Issues Preliminary Findings**

**ARB Contract No. 09-410**

**Maritime Air Quality Technical  
Working Group Meeting**

**April 28, 2010**



***California Maritime Academy***

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## **Background/Overview**

**OGV Clean Fuel Regulation  
Investigation of Operational Issues  
Air Resources Board Contract No. 09410**

- This project is designed to support the implementation of the California Air Resources Board (ARB) ship fuel regulation, which began on July 1, 2009.
- While most vessel operators are successfully complying with the regulation, some operators have reported operational difficulties that may be related to the use of the distillate fuel.
- Although the number of vessel incidents appears to be decreasing as vessel operators adjust to the new requirement, ARB has contracted with the California Maritime Academy (CMA) to investigate these incidents.

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**OGV Clean Fuel Regulation  
Investigation of Operational Issues  
Air Resources Board Contract No. 09-410**

- Under this contract CMA will perform the following:
  - Task 1: Identify Root Causes of Operational Difficulties or Incidents
  - Task 2: Identify Lessons Learned by Vessel Operators
  - Task 3: Prepare a Technical Report Summarizing Findings and Recommending Solutions

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## **Task 1**

### **Identify Root Causes of Operational Difficulties or Incidents**

- Analyze available information:
  - United States Coast Guard (USCG) casualty reports
  - Industry responses to an ARB survey of vessel operator experience with the low sulfur fuel.
  - Contacts with shipping lines
  - USCG staff who have conducted vessel casualty investigations
  - Engine manufacturers
  - Marine engineers
  - Others, as needed.

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## **Task 1**

### **Identify Root Causes of Operational Difficulties or Incidents** (continued)

- Investigations will ideally lead to root causes such as:
  - Equipment type (e.g. fuel injection pumps)
  - Make/model/age of equipment affected
  - Fuel switching procedures
  - Maintenance practices
  - Crew Training

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## **Task 2**

### **Identify Lessons Learned by Vessel Operators**

- Through contact with the shipping lines/vessel operators, CMA shall identify strategies that have been used to avoid vessel incidents based on operators' experience to date using the distillate fuel.
- These strategies may include changes in:
  - Vessel maintenance practices.
  - Fuel Switching procedures.
  - Increased crew training.
  - Fuel Sourcing (e.g. purchasing higher viscosity distillate fuels)

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## **Task 3**

### **Prepare a Technical Report Summarizing Findings & Recommending Solutions**

- Under this task, CMA shall prepare a technical report summarizing the findings in Tasks 1 and 2, and then recommend solutions.
- The report will include a summary of the most recent information on operational difficulties and vessel incidents that have occurred since the Ship Fuel Rule was implemented, and the extent to which these incidents could be related to the use of low sulfur fuel.

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**Task 3**  
**Prepare a Technical Report Summarizing Findings & Recommending Solutions** (continued)

- The contractor will also put these incidents into perspective by:
  - Comparing them to other sources of vessel incidents that have occurred, both during and prior to the implementation of the rule.
  - Identify any trends in vessel incidents.
- Based on this information, CMA shall recommend actions that the shipping lines can take to prevent operational difficulties.

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**Reported Operational Problems**

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## Loss Of Propulsion Incidents Related to Fuel Switching

- While there have been vessels which have had difficulty operating on light distillate the majority are successfully operating on this fuel.
- What are the problems that have been reported when burning low-sulfur distillate and how can they be avoided or minimized?

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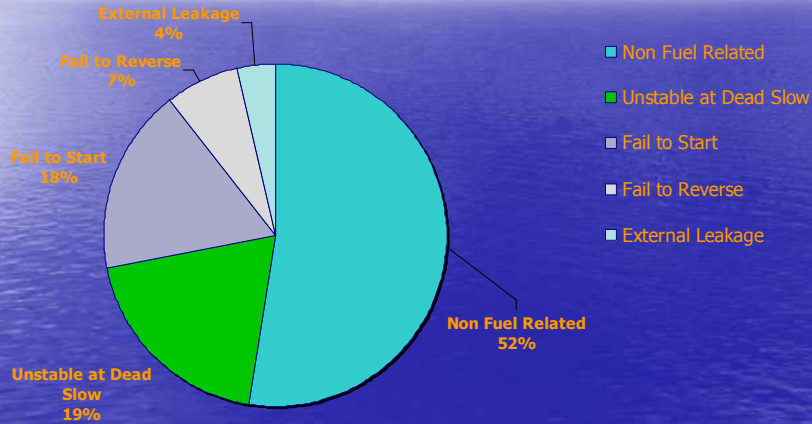
## Reported Operational Problems

- **Fail to Start** – main engine will not start on light distillate.
- **Unstable at Dead Slow** – main engine RPM varies or the engine stalls when running at Dead Slow. Engine will run reliably at higher speeds.
- **Fail to Reverse** – main engine can run at low loads and does start normally. However it cannot start in the astern direction due to wind milling effect of propeller when vessel is underway above a certain speed.
- **External Leakage** – Leaking O-rings on fuel valve (fuel injector) causing excessive fuel leakage & leakage on high-pressure manifold. Loss of propulsion was due to a voluntary shut-down of the main engine to repair leakage before vessel proceeded to its destination.

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## United States Coast Guard Loss of Propulsion Incidents in California

(July 1, 2009 to March 31, 2010)



U.S. Coast Guard District 11, SF Bay Region and LA/LB, Loss of Propulsion incidents where the use of distillate fuel was a contributing factor

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## Engines Involved in LOP Incidents

- To date all of the vessels reporting a loss of propulsion have utilized the 2-stroke cycle slow-speed crosshead type diesel engine for propulsion.
- No apparent trends with 2-stroke slow-speed marine engine make or model (other than percentage of engines in the fleet visiting California)

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## **Additional Problems Reported in the ARB Survey**

- Seizure of high-pressure fuel pump plungers or injector needle valve.
- Leaking fuel system circulating gear pump shaft seals.
- Low fuel system operating pressure due to either excessively worn circulating pumps or back-pressure regulating valve.
- One company reporting that vessel design did not incorporate a sufficiently large diesel oil service tank or fuel separators to run for extended periods on light distillate.

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## **Possible Underlying Problems**

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## Possible Underlying Problems

- Viscosity Issues
- Fuel Pump Internal Leakage
- External Leakage
- Procedures / Crew Training

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## Viscosity

- The viscosity of heavy residual fuels is maintained between 10 and 15 cSt.
  - If the fuel viscosity exceeds 15 cSt the fuel may not atomize properly in the combustion chamber.
  - The fuel will lose its ability to lubricate the high-pressure fuel pump plunger and barrel if the viscosity drops below 10 cSt.
- Light distillate viscosity should be kept above 2 cSt.
  - The viscosity should be maintained above the minimum to maintain fuel lubricity and prevent excessive leakage in the high-pressure fuel pump.
  - At low engine loads the circulation of distillate through the high-pressure pumps may heat the circulating fuel and cause its viscosity to drop excessively.

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## **Effect of the Fuel System on Viscosity**

- Inability to maintain the viscosity of light distillate fuel above 2 cSt at low engine loads has a significant impact on the operation of the high-pressure fuel system.
  - At low loads or when the engine is stopped, the fuel continues to be circulated through the system picking up heat.
  - Even with all of the system steam tracing turned off, circulation through the high-pressure pumps and fuel valves can increase fuel temperature.

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## **Typical Pressurized Fuel System Design Criteria**

- The fuel system for a modern heavy fuel diesel engine has standard features to insure reliable engine operation.
- To accurately maintain the viscosity within a narrow range the fuel is continually being circulated.
- Modern systems are designed to handle fuel with viscosities as high as 700 cSt at (50° C).

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## **Pressurized Fuel System**

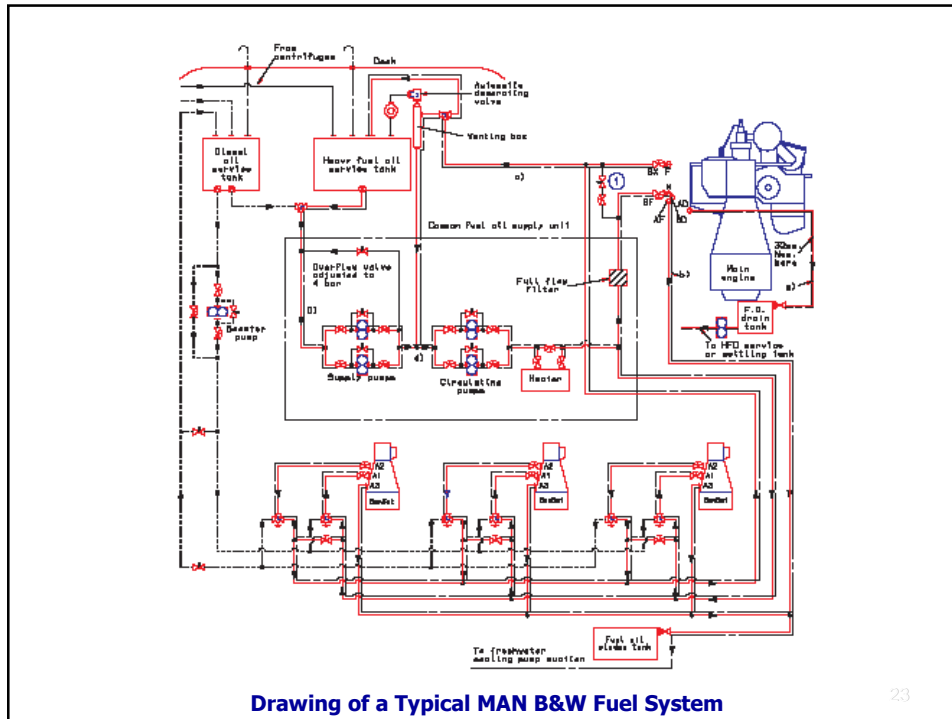
- Viscosity must be maintained throughout the entire fuel injection system even when the main engine is stopped.
- All the system tanks and fuel lines are heated by either low-pressure steam or hot jacket water.
- To prevent the formation of vapor in the circulating system, a fuel supply pump increases the pressure of the fuel entering the circulating system to a typical pressure of 4 bar.

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## **Heating of the Distillate At Low Engine Loads**

- A circulation system is necessary to insure proper operation of the diesel engine at all load conditions when burning HFO.
- An undesired effect of the circulating system is that distillate fuel can pick up heat from injection equipment as it is circulated.
  - The temperature of fuel injection components will be close to the temperature of the engine jacket cooling water (80° C).
  - The result is an undesirable drop in the viscosity of the distillate fuel even with all the system heating sources shut off.

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## Marine Diesel Engine Fuel Recirculation System

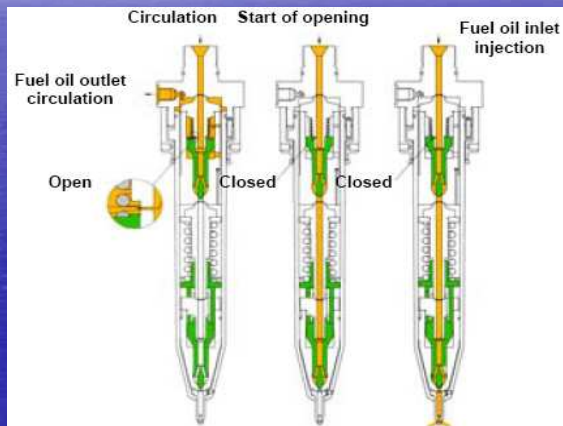
- When the engine is stopped fuel can flow through the high-pressure fuel pump suction valves and into the pump barrel.
- From the pump the fuel flows through the high-pressure pipe and into the fuel injector.
- The non-return valve mounted at the top of the fuel injector directs the flow through the fuel outlet connection where it returns back to the system.

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## Marine Diesel Engine Fuel Recirculation Systems



MAN B&W High-Pressure Fuel Pump



MAN B&W Fuel Valve Showing Fuel Circulation Paths

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## High-Pressure Fuel Pump Internal Leakage

- Excessive internal leakage between the high-pressure pump plunger and barrel.
  - This problem is most likely the root cause for the majority of the LOP incidents.
  - The thinner the fuel, the more leakage will occur decreasing fuel injection pressures.
- An engine with worn high-pressure fuel pumps may run at higher speeds but will have difficulty starting or running at dead slow.
  - Fuel injection pressure of mechanically actuated fuel pumps tends to be lower at low engine revolutions due to decreased plunger velocities.

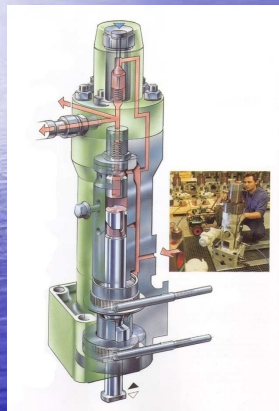
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## High-Pressure Fuel Pump O-Ring Internal Seal Leakage

- Leaking seals for the puncture valve may be observed by the external leakage or by the increased flow rate into the fuel catch tank.
- A leaking O-ring seal in the suction valve may reduce injection pressures which would be indicated by a drop in exhaust temperature.

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## Determining the Condition of the High-Pressure Fuel Pump



MAN B&W High-Pressure  
Fuel Pump

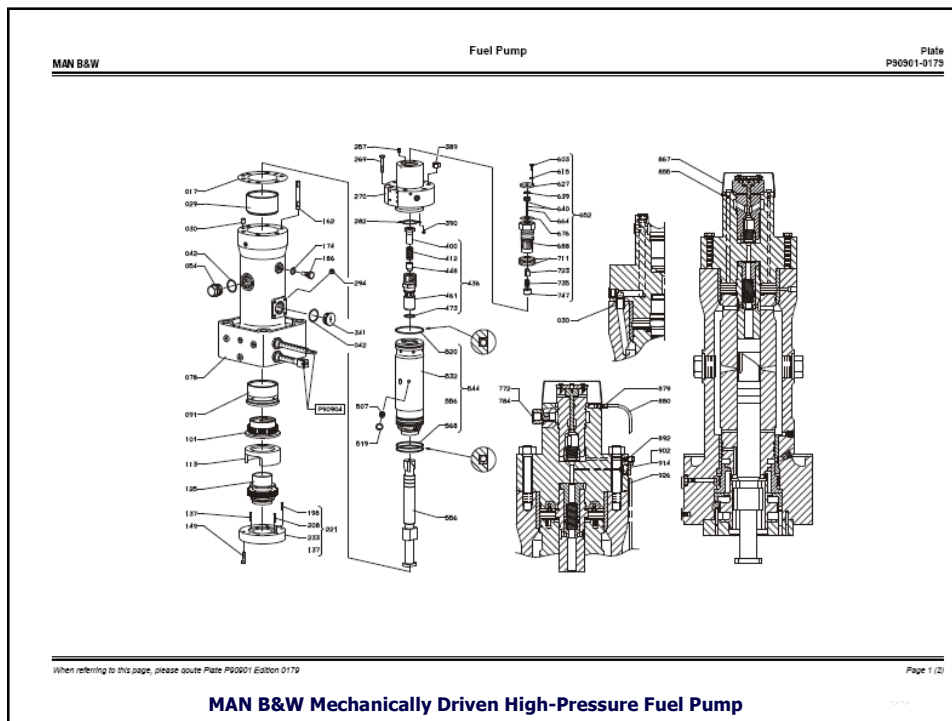
- Worn fuel pumps and leaking suction valves will show up as an increased fuel index in relation to the mean pressure.
- The manufacturer recommends overhauling the pumps when the index has increased by about 10%.
  - Compare the current fuel index to testbed documentation.

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## High-Pressure Pump Fuel Index

- The fuel pump index is dependent on:
- Amount of pump wear.
  - The viscosity of the fuel oil.
    - ✓ Low viscosity will increase leakage in the fuel pump, and thereby necessitate higher indexes for injecting the same volume.
  - The calorific value and the specific gravity of the fuel oil.
    - ✓ These will determine the energy content per unit volume and can therefore also influence index.
  - All parameters that affect the fuel oil consumption
    - ✓ (ambient conditions, pmax, etc.)

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## External Leakage

- Excessive external leakage of fuel due to leaking seals and O-Rings.
  - The light distillate can act as a solvent removing hardened deposits left by residual fuels.
  - The viscosity of the light distillate is much lower allowing for a larger quantity of fuel to leak past.
  - Sealing O-rings can lose their elasticity and ability to seal properly due to the high temperatures to which they are exposed.
    - ✓ Changing fuel temperatures cause expansion & contraction of fuel system components. The O-rings are not able to conform to the changes and leakage occurs.

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## Preliminary Findings, Solutions or Recommendations

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**Preliminary Findings, Solutions or Recommendations**  
**Pre-Testing & Pump Maintenance**

- Performing a test-run on light distillate fuel prior to the vessel entering a maneuvering situation is absolutely vital.
  - This step would provide invaluable training to the vessel crew and would provide them with an opportunity to repair any problems that are revealed as a result.
  - During this pre-test the condition of the high-pressure fuel pumps should be checked to determine that the internal leakage will not be excessive on the less viscous distillate fuel.

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**Preliminary Findings, Solutions or Recommendations**  
**Issues Concerning Procedures and/or Crew Training**

- It is essential that the vessel is supplied with written fuel change-over procedures that follow engine manufacturer's guidelines.
  - These guidelines should be specific to the actual shipboard systems if they deviate from the standard recommended fuel system.
- The engineering crew must fully understand the procedures and know the locations of all pertinent system valves and equipment.
- When shifting from heavy residual fuel to light distillate, all fuel line steam tracing should be turned off prior to change-over.

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**Preliminary Findings, Solutions or Recommendations**  
**Issues Concerning Procedures and/or Crew**  
**Training** (Continued)

- Fuel viscosity must be maintained within manufacturer's recommendations throughout the change-over process.
- With low viscosity fuels, the diesel oil day tank should be maintained at as low a temperature as possible.
- As an option, the engine manufacturers can provide equipment which has been designed to automate the change-over process.
  - Modern fuel systems react very quickly to any change and this option would greatly assist the crew in maintaining fuel viscosity and temperature during this transition period.

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**Preliminary Findings, Solutions or Recommendations**  
**Viscosity**

- When ordering bunkers, the vessel operator should specify low-sulfur distillate with as high a viscosity as possible.
- The viscosity of the distillate fuel should never be heated within the fuel system to the point that its viscosity drops below 2 cSt.
- If the viscosity of the fuel cannot be maintained above 2 cSt due to the absorption of heat within the fuel circulating system, the addition of a heat exchanger to cool the fuel would alleviate the problem.

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#### Preliminary Findings, Solutions or Recommendations

### Viscosity (continued)

- The maintenance schedule for fuel injection equipment will need to be adjusted to insure that excessive internal leakage does not occur.
  - Since the distillate fuel is thinner, the volume of leakage past any gap will be greater.
  - The amount of allowable wear for fuel pump and fuel valve (injector) components will be correspondingly less due to the viscosity of the distillate.
  - The manufacturers' guidelines should be used as a starting point and adjusted over time as experience is gained with engine operation on distillate fuel.

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#### Preliminary Findings, Solutions or Recommendations

### External Leakage

- Any system leakage should be repaired prior to burning light distillate as the less viscous fuel tends to remove heavy fuel deposits thereby increasing the volume of the leak.
- Check the general condition of fuel system sealing O-rings to check for loss of elasticity or cracking.
- Check that the fuel rack moves easily without binding and the pre-set governor speed setting is correct.

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## O-Ring Seal Leakage

- Before operating on light distillate fuel for the first time, it may be beneficial to sample the condition of fuel pump O-ring seals by removing a seal from the oldest pump to determine if the elasticity of the seals is adequate. Check to see that the seal is still flexible and look for any signs of cracking.
- If the sample seal is not in good condition, it may be advisable to replace all seals prior to running on light distillate fuel.

## Improper Governor Pre-set Speed Setting or Binding of the Fuel Rack

- Failure to start may be associated with insufficient fuel delivery.
  - Check that the pre-set governor speed setting pressure is not set too low or for too short a time period.
  - Insure that there is no binding in the fuel pumps, rod connections, or bearings.
- If the engine fails to start on *Bridge* control, switching to the *Engine Room Console* may allow the engine to start in some instances.

### Preliminary Findings, Solutions or Recommendations

## Engine Control

- Until the starting characteristics of the engine on light distillate are proven:
  - Transfer control to the engine control room when reversing the main engine while under way.
    - ✓ This will allow the engineers to increase the starting fuel setting if the engine does not start on the first attempt.
- Vessel engineers should be experienced in controlling the engine from both the engine control room and from the engine side.

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## Next Steps

- Identify lessons learned by vessel operators.
  - Identify strategies that have used to avoid vessel incidents based on operators' experience while using distillate fuel.
    - ✓ These strategies will include vessel maintenance practices, fuel switching procedures, increased crew training, and fuel sourcing (e.g. purchasing higher viscosity distillate fuels).
    - ✓ Gather information by direct observation aboard vessels during their transit to and from California ports.
    - ✓ Talk with vessel chief engineers about their experiences with distillate fuel and how engine maintenance has been adjusted to accommodate the change in fuel.
- Prepare a technical report summarizing findings and recommending solutions.

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